Anuário do Instituto de Geociências
Universidade Federal do Rio de Janeiro
https://revistas.ufrj.br/index.php/aigeo/

ISSN 0101-9759
e-ISSN 1982-3908

Morphodynamic and Climatic Control on Sandy Beaches: Challenges of Geoenvironmental Studies for the Conservation of Biodiversity and the Maintenance of Ecosystem Services

Controle Morfodinâmico e Climático em Praias Arenosas: Desafios dos Estudos Geoambientais para a Conservação da Biodiversidade e a Manutenção dos Serviços Ecossistêmicos

Anderson Abbehusen Freire de Carvalho & Iracema Reimão Silva

Universidade Federal da Bahia, Instituto de Geociências, Programa de Pós Graduação em Geologia, Núcleo de Estudos Hidro geológicos e do Meio Ambiente - NEHMA, Salvador, Bahia, Brasil
E-mails: andersonabbehusen@gmail.com; iracemars@yahoo.com.br

Resumo

As praias arenosas podem ser divididas em dois ecossistemas praiais: os autossustentáveis e os de interface, que respondem de forma diferente ao controle mofordinâmico e climático sobre a biodiversidade. Os principais fatores que atuam sobre a biodiversidade das praias arenosas são a energia das ondas e a ação dos ventos, que são responsáveis pela movimentação do sedimento e a determinação do relevo da praia. As variações climáticas, a exemplo das tempestades, também influenciam de forma significativa a dinâmica dos ecossistemas praiais. Mesmo possuindo um equilíbrio ecológico delicado, as praias arenosas não têm sido reconhecidas como áreas prioritárias para conservação, talvez pela ausência de uma cobertura vegetal exuberante ou pela pouca percepção da sua biodiversidade. Para boa parte da população que frequenta as zonas costeiras, as praias arenosas aparentam ser um sistema biologicamente pobre e valorizado apenas pelos aspectos paisagísticos e de recreação. O uso recreativo intenso e a ocupação desordenada do pós-praia aumentam os impactos sobre esses ambientes, alterando a deposição de sedimentos, dificultando o deslocamento da biota e aumentando os processos erosivos, comprometendo a funcionalidade ecossistêmica. Diante deste contexto, se faz necessário realizar estudos de indicadores que possam fomentar estratégias adequadas para a gestão costeira, preservando o equilíbrio dos ecossistemas e a manutenção dos seus serviços, inclusive os considerados essenciais para a espécie humana. A presente revisão tem como objetivo principal discutir como os processos geoambientais, a exemplo dos morfodinâmicos e climáticos, atuam sobre a biodiversidade das praias arenosas e como estes fenômenos podem influenciar o equilíbrio ecossistêmico e a oferta dos seus serviços. Dentro desse cenário também foi discutido as possíveis interferências das alterações climáticas, a ocupação desordenada dos ambientes costeiros e suas implicações para conservação das praias arenosas.

Palavras-chave: Praias Arenosas; Controle Morfodinâmico; Conservação Costeira

Abstract

Sandy beach can be divided into two beach ecosystems: self-sustaining and interface, which respond in different ways to morphodynamic and climate control on biodiversity. The main factors which act upon sandy shore biodiversity are wave energy and wind action, which are responsible for the movement of sediment and the determination of beach inclination. Climactic variations, such as storms, also significantly influence the dynamic of sandy shores. Although they have a delicate ecological balance, sandy shores have not been recognized as priority areas for conservation, possibly due to the absence of exuberant vegetation cover or due to the lack of perception of their biodiversity. For the majority of people that frequent coastal areas, sandy shores appear to be poor biological systems and are valued only for scenic and recreational purposes. Intense recreational use and the unorganized use of the backshore increases the impacts on these environments, altering sediment deposition which increases the difficulty of biota movement and increases erosion processes, compromising ecosystem functionality. It is therefore, necessary to research indicators which can result in the creation of effective strategies for coastal management, preserving ecosystem balance and the maintenance of its services, including those considered essential for the human race. This revision principally aims to discuss how morphodynamic and climactic processes act upon sandy beach biodiversity and how these phenomena can influence ecosystem balance and the offering of their services. We also discuss the possible interferences of climactic alterations, unorganized occupation of coastal environments and their implications for the conservation of sandy shores.

Keywords: Sandy beaches; Morphodynamic control; Coastal conservation

1 Introduction

Sandy beach environments are made up of dynamic systems where natural factors such as wind, water and sand interact, resulting in complex hydrodynamic and depositional processes (Brown & McLachlan, 2002). They comprise a subaerial portion (supra and mediolittoral) and a subaquatic portion which includes the surf zone and extends to the orbital base of waves (Wright & Short, 1984).

Wave energy released in coastal zones is the principal factor in determining the diverse profile of beaches along the coast. These beaches range from very exposed to very sheltered and vary physically, resulting in the combination of basic parameters, such as wave characteristics and sediment granulometry, which in turn depend on background morphology, circulation pattern and current dynamics (McLachlan & Brown, 2006). According to the degree of intensity of these factors, beaches can be classified as morphometric in two extreme states: dissipative and reflective (Calliari & Klein, 1993; Bentes et al., 1997; Hoefel, 1998).

With regards to coastal ecosystems, McLachlan & Brown (2006), based on the morphodynamic classification scheme of Wright & Short (1984), considered the existence of two types of beach ecosystems: the beach interface ecosystem, typical of low energy beaches; and the self-sustaining beach ecosystem, typical of high energy sandy shores and fine sand. In terms of trophic dynamics, the differences between these ecosystems lie in the type of main food sources available according to morphodynamic parameters. In beach interface ecosystems, the main food sources are stranded vegetation and marine or terrestrial animals (McLachlan & Brown, 2006), demonstrating the importance of the supra littoral and the backshore in the maintenance of beach biodiversity. On the other hand, self-sustaining beach ecosystems are favored for the appearance of primary producers such as diatoms, which end up supporting a complex food web. In this way dissipative beaches tend to present a greater biodiversity when compared to reflective beaches (McLachlan & Brown, 2006). As such, the interaction of morphodynamic characteristics, such as wave height, tidal energy and the size of available sediments, as well as determining the physical characteristics of the sandy shores (Wright & Short, 1984), also interfere in the structure of biodiversity and in the dynamics of beach ecosystems. These relationships are so implicit that Calliari *et al*. (2003) state that the prior classification of beaches, according to their dynamics, is fundamental for more consistent studies of biodiversity.

Climactic factors, such as storms, also influence biodiversity (Caló *et al*., 2005). The action of climactic factors is capable of modifying morphodynamic characteristics and biodiversity structure, since they alter the energy that these environments are submitted to, allowing for the increase of sediment transport and erosion processes.

The IPCC (2013) projections are that sea level will rise faster than expected for the next century and will continue to rise for a long time (Oppenheimer et al, 2019; Brown & McLachlan, 2002). The IPCC reports indicate that coastal ecosystems are already impacted by the combination of the SLR (relative sea level rise), other climate changes related to climate and anthropogenic actions, mainly the construction of coastal infrastructure and habitat degradation. With the predicted global climate changes over future decades and the expected rise in sea level, there is a tendency, in the long term, towards the erosion of the backshore (Figure 1).

The rise in sea level may also interfere in the frequency and intensity of storms, resulting in a loss of habitat (Brown & McLachlan, 2002), which is an important ecosystem service provided by these environments. Brown & McLachlan (2002), comment that it is not expected that the predicted temperature changes will have significant effects on beaches across the world, however, in the long term there is a predicted increase in ultraviolet radiation (UV) which, certainly, in association with environmental changes promoted by global warming, will have consequences on the preservation of sandy shore biodiversity and above all on productive rates and ecosystem balance. Although sandy shores have a reasonable biological diversity and a delicate ecological balance due to their dynamics, they have not been recognized as priority areas for conservation. This may be due to the absence of exuberant vegetation cover or due to lack of perception of sandy shore biodiversity, which is made up primarily of meiofauna organisms that live buried under sand and often go unnoticed due to their cryptic coloration, reduced size or digging behavior (Veloso *et al*., 1997; Blankensteyn, 2006; Villar de Araujo *et al*., 2008). For the majority of the population that frequent coastal zones, beaches appear to be a biologically poor ecosystem and are only valued for their scenic and recreational aspects (Figure 2).

For being a dynamic environment, sandy beaches are sensitive to anthropic interventions, especially the construction of structures to contain coastal erosion such as break seas and jetties, which influence the horizontal mobility of the coastline causing impacts on beach morphology such as decreasing the width of the coastline beach and reduction of slope on the beach face (Koerner et al, 2013). The disordered occupation of the backshore, associated with intense recreational use, also increases the impacts on these environments and changes the deposition of sediments, reducing the available resources, increasing the difficulty of moving the biota and increasing the erosive processes.

Figure 1 The advance of the erosion process on the backshore, Praia do Forte, Bahia – Brazil (Photograph taken by author).

Figure 2 Recreational and unorganized occupation of beach environments, Praia do Forte, Bahia – Brazil. (Photograph taken by author).

This review, therefore, aims to discuss how the morphodynamic and climatic processes act on the biodiversity of sandy beaches and how these phenomena can influence the balance of the ecosystem and the availability of its services. We also discussed possible interference from climate change, disorganized occupation of coastal environments and its implications for the conservation of sandy beaches.

2 Methodology

For the development of this article, we did a great amount of research using the the Higher Education Personnel Coordination Foundation – CAPES journal portal, associated with the Brazilian Ministry of Education, where, as well as the classic publications which are timeless references on this subject, we searched for publications from the last 20 years through the keywords "sandy beach conservation", " sandy beach morphodynamic control" and "sandy beach biodiversity". Only articles in English and Portuguese were selected and the search was refined with the topic "biodiversity". From the reading of the title or abstract, priority was given to manuscripts that met the inclusion criteria: 1) articles that discussed the responses of the biological community to variations in morphodynamic and climatic factors; 2) articles that discussed the management of sandy beaches and the maintenance of their services.

3 Results and Discussion

3.1 The Influence of Morphodynamics on Sandy Beach Biodiversity

Sandy beach fauna is comprised of resident animals, usually forming aggregated patterns of internal distribution which, according to their way of life, is made up of epifauna and infauna. They are organisms that have special adaptations compared to animals from other ecosystems, as they depend on the hydrodynamism of the beach and are subject to substrate instability and wave action (Coutinho, 2013). According to Coutinho (2013), the mobility of these organisms must be fast and efficient to allow them to construct shelters and to maintain their positions in the sand, as a result they avoid being swept away by waves and spray. They have quick responses to environmental stimuli and are adapted to varying tide levels, maximizing food resources and reducing predation (McLachlan & Brown, 2006).

These organisms are also influenced by salt variation and must avoid desiccation. They are distributed in different ways across zones varying between the sublittoral and the supralittoral. Their biodiversity tends to increase towards the sublittoral zone, in areas close to the waterline, which suffer the most from wave and tidal action, allowing other species to invade the intertidal zone originating from the surf zone (Brown & McLachlan, 2002).

The majority of these fauna are miniscule, difficult to quantify and live between grains of sand. Macrofauna are easier to see and are represented by the majority of invertebrate taxonomic groups, with the numerically most important groups being Polychaeta, Mollusca and Crustacea (Brown and McLachlan, 1990; Degraer *et al*., 2003). As well as resident organisms, sporadic visiting organisms or organisms that use beaches as an essential food source, must also be considered (Brown & McLachlan, 1990) since they can expressively elevate the diversity and abundance of beach fauna.

Beach zones or ecosystems can be molded by wave energy, which moves sediment in a significant way. The occurrence of climate change can accelerate this process. In relation to these alterations, Brown & McLachlan (2002), commented on the importance of storms in influencing the molding stage of beaches and in the definition of these ecosystems. When the greatest movement of sand occurs, large quantities of sediment can be removed from the upper margin and deposited in the surf zone (Carcedo *et al.*, 2014), increasing wave energy (Masselink & Short, 1993). Furthermore, waves are capable of moving sediment from the sublittoral zone, depositing it in the intertidal zones.

Another important factor is marine currents. Carcedo *et al.* (2014), after performing studies along the Argentinian coast, commented on the influence of these currents on the exportation of warm water, which is a process that not only results in increased temperatures in the surf zone but also elevates suspended sediment loads, allowing for the occurrence of some non-resident invertebrates typical of other ecosystems, such as some cnidarians and crustaceans typical of estuaries (Gibbins *et al*., 2007; Elías *et al*., 2007; Hoffmeyer & Mianzan, 2007).

In the intertidal zone, sediments can be subjected to seasonal accretion and erosion events related to rainfall patterns, which reduce the occurrence of some benthic taxa (Souza, 2009; Lamour & Soares, 2003). This is most likely due to the fact that rain can also transport sediments and momentarily alter salinity. This dynamic, particularly the movement and deposition of sediment, determines environmental heterogeneity which is responsible for the spatial distribution of benthic populations and for the flux of organisms between shore zones (Brown & McLachlan, 2002; Pagliossa, 2006; Corte *et al.*, 2017). Wave energy also allows the rise of water in intertidal zones to influence the presence of interstitial water and consequently the availability of food for beach ecosystems.

Macrofauna in the intertidal zone can be characterized as a community with little diversity, reduced richness and elevated numerical dominance of few species, when compared to macrofauna in submersed regions. Finer grains allow for greater moisture retention, favoring microorganism action, mainly bacteria and protozoans, responsible for the degradation of organic material and consequently nutrient availability for the other adjacent trophic levels (Brown & McLachlan, 2002). Interstitial moisture also avoids the drying of more sensitive organisms in higher temperatures. Additionally, organisms are distributed in different ways between coastal zones, according to developmental stage, such as the crab *Ocypode quadrata* (Fabricus, 1787). Larger individuals have the ability to construct deeper burrows, which allows for the maintenance of ideal moisture levels for their survival even in areas further away from water whereas, smaller individuals are predominant near water due to the greater abundance of food and their diminished capability of digging, reducing their susceptibility to drying out (Alberto & Fontoura, 1999; Vilar de Araújo, 2008).

The movement and deposition of sediments from wave action, influence the beach inclination. The bigger the grain size, the steeper the profile will be (Villwock, 1994). Steeper beaches, associated with bigger grains, allow for greater water flow, contrary to flatter beaches with finer grains, which allow for a better retention of moisture. In this way, there is a strict relationship between inclination and biodiversity: the greater the decline, the lower the diversity and abundance of species (McLachlan & Brow, 2006).

In general, when dealing with biological variables, the number of species is more affected by physical and morphodynamic factors, increasing linearly with tide amplitude and decreasing with average grain size. In the case of biomass, there is an exponential decrease with the increase of grain size. These tendencies, according to Rodil and Lastra (2004), corroborate multiple previous studies in different coasts around the world, where thick sand limits benthic macrofauna. Dissipative beaches, where grains are finer, the inclination is lesser and wave energy is greater, tend to have a greater number of species, greater abundance and greater biomass, as well as having more favorable conditions for larval recruitment (Defeo & McLachlan, 2005; Coutinho, 2013). All the taxonomic categories present the same tendency of increasing richness and abundance in dissipative beaches, although responses to grain size and shore inclination are less accentuated in crustaceans and insects compared to molluscs and polychaetes (Barbosa *et al*., 2012), probably due to the latter being less efficient in terms of mobility.

For beaches in modest reflective or intermediate stages, there is a significant influence of stranded organic debris, especially macrophytes, on macrofauna species' (mainly aphopods, isopods and insects) biomass, richness and abundance (Lecari *et al*., 2010). Associated with the presence of invertebrates, are vertebrate predators that have increased populations, such as waders, that prey upon these invertebrates. Strandings are also important for the maintenance of macrofauna structure in upper trophic levels and in sandy shore ecological processes, as they serve as food and shelter for many invertebrates. As well as their occurrence in reflective beaches, waders also visit dissipative beaches in search for areas to rest and feed, taking advantage of the greater abundance of organisms (Cestari, 2008). On the backshore, the occurrence of other predatory organisms influenced by this food chain, such as the wolf-spider, (*Allocosa brasiliensis*, Petrunkevitch (1910)), can be found in more conserved environments (Jorge *et al*., 2015). Beach ecosystems are also sought out by some reptile and mammalian species in search of food. Whereas, marine turtles use them as an area for depositing their eggs and their reproductive process is made possible through certain characteristics such as temperature and inclination.

Studies by Lecari *et al*. (2010), concluded that greater diversity and biomass in dissipative beaches, reflect the complexity of these ecosystems. The results of their study revealed, for example, a greater number of predators in upper trophic levels in dissipative beaches (marine birds, fish, gastropods and polychaetes) compared to in reflective beaches. Organisms of intermediate trophic levels (detritivores and benthic invertebrates), can be found both on dissipative and reflective beaches, with both types of beaches having primary production and the exportation of detritus to adjacent trophic levels in common. It is therefore, possible to observe the existence of strong correlations between the modal state of beaches, species richness and macrofauna abundance (Brown & McLachlan, 2002; Rodil & Lastra, 2004), with coastal ecosystems playing an important role in the maintenance of coastal biodiversity. As well as playing an important role in providing habitats for many species, the complexity of trophic flow between the various shore zones can also be observed, including the feedback of sublittoral and surf zone biota, which results in these ecosystems providing food for human populations that inhabit the coastal environment, for subsistence farming or for the trade of some species.

3.2 Effects of Climate Change

The increase in extreme climate change is predicted for the 21st century, including changes in the frequency and intensity of storms (IPCC, 2013; Corte *et al*., 2017). These global changes in the physical and chemical conditions of ecosystem are causing innumerous biological impacts in both terrestrial and marine environments. As a result, current studies on seasonal climate influence can generate models that allow for the understanding of how biodiversity will react to these predicted alterations, specifically for storms and wind patterns, since these modify wave energy, marine current flow and rain patterns, causing significant changes in coastal environments (Mateo & Garcia-Rubies, 2012), mainly due to the translocation of sediments between the various shore zones (Masselink *et al*., 2016).

These phenomena cause significant changes to habitats which are generally accompanied by strong impacts on biological communities (Lucrezi *et al*., 2010; Jaramillo *et al.*, 1987; Jaramillo *et al.*, 2001; Mateo & Garcia-Rubies, 2012; Corte *et al*., 2018), even though species typical of coastal ecosystems are well adapted to high energy conditions and are able to recuperate in a relatively quick way from the majority of storm events (Harris *et al.*, 2011; Schlacher & Thompson, 2013; Machado *et al*., 2016; Corte *et al*., 2017). Several studies have previously indicated that the necessary time for the recuperation of biodiversity depends on the magnitude, scale and frequency of disturbance events (Lucrezi *et al*., 2010; Urabe *et al*., 2013; McClain & Schlacher, 2015; Schlacher *et al*., 2015) and that depending on the taxon, the recuperation can take one day (Gallucci & Netto, 2004) weeks (Machado *et al*., 2016) or years, in the case of extreme events that severely compromise the spatial and trophic structure of ecosystems (Jaramillo *et al*., 1987; Mateo & Garcia-Rubies, 2012).

These studies suggest that all the principle groups of microbenthic organisms suffer a decrease in richness following a storm, especially crustaceans which as well experiencing a decrease in richness, suffer a drastic reduction in abundance and biomass. The influence of these events is mainly on smaller species with less mobility, since they are more exposed to sediment erosion (Nuci *et al*., 2001; Negrello Filho & Lana, 2013; Urabe *et al*., 2013; Corte *et al*., 2017). Studies by Corte *et al*. (2017) on the effects of storms, in sedimentary tidal plains in southeastern Brazil, showed fewer polychaete species and lower biomasses after these events, on mostly small and tubular forms. On the other hand, the same studies showed that opportunistic polychaete species (Pearson & Rosenberg, 1978) increased in abundance after storms. Molluscs did not suffer significant changes in biomass, most likely due to the fact that they are heavier and are less susceptible to movement through turbulent currents caused by storms (Corte *et al*., 2017). These characteristics indicate that sandy shores, although seemingly biologically inhospitable environments, can have diverse and well adapted fauna. Phenomena of atmospheric turmoil, such as storms, can increase wave energy and wind force, as well as momentarily elevating sea level. These alterations determine the massive and sporadic presence of non-resident species that move together in the sediment, coming from other environments such as the sublittoral zone and areas adjacent to the surf zone (Caló *et al*., 2005) for example estuaries (Luzzatto, 2006; Muniain *et al*., 2007) and rocky bottoms (Bremec *et al*., 2013).

Wind action has often received little attention compared to other aspects associated with climate change, such as global warming and rising sea levels. Wind has a fundamental role in the formation and increase of wave energy, since waves are formed due to the transfer of atmospheric movement to the ocean surface, distributing heat and impulse between these two environments (Semedo *et al*., 2013; Dobrynin *et al*., 2015). Although not all scholars agree, studies predict changes in the intensification or weakening of wind systems (Sydeman *et al*., 2014). Changes in wind direction are also worrying in coastal regions, where the wind influences hydrodynamic agents (McInnes *et al*., 2011). In this way, meteorological tides, waves and changes in storm occurrence and intensity can all be influenced by these conditions (Fernandino *et al*., 2018), which drastically affect sediment transport, leading to an increase in erosion processes and impacts on coastal biodiversity.

Coastal ecosystems tend to respond differently based on their modal state. In exposed oceanic beaches, species are well adapted to the high energy conditions, suffering more significant impacts on the environment (Brown & Mclachlan, 1996; Schlacher & Morrison, 2008), increasing for example, erosion processes. Cochôa *et al*. (2006), Alves & Pezzuto (2009), Harris *et al*. (2011), on studying the influence of storms on coastal ecosystems, also showed that storms can have stronger impacts on the environmental characteristics than on the fauna. In contrast, studies performed by Corte *et al*. (2017), showed that under more sheltered conditions, the impact of storms were more evident for fauna than for the environment.

Unfortunately, the consequences of storms on the functionality of coastal ecosystems are still largely unknown, including the impacts on ecosystem services, such as coastal protection and fishing. Future studies should therefore, aim to prioritize investigating how ecological processes in coastal ecosystems respond to extreme events and which parameters determine their resilience and recuperation (Corte *et al*., 2017).

As well as changes created by morphodynamics and climactic phenomena, salinity can also be a critical variable that can affect biodiversity patterns (Schoeman & Richardson, 2002; Ortega *et al*., 2011; Barboza *et al*., 2012), as it drastically influences the osmotic balance of organisms. Studies by Barbosa *et al*. (2012), in beaches of different morphodynamic states, indicate that species richness is strongly affected by simultaneous variations in morphodynamics and salinity, since different groups of species can present different richness patterns in response to these environmental variables. Species richness was found to be lower for intermediate salinities, increasing in the direction of environments with oceanic estuarine conditions. Organisms' tolerance to changes in salinity associated with organism habitat and developmental stage, which determines the degree of fauna group sensibility to osmotic stress, has also been observed (Barboza *et al*., 2012).

Studies by Lecari & Defeo (1999), on sandy shores and by Atrill (2002) in estuarine environments, showed that variations in salinity can provoke alterations in abundance and distribution of macrofauna elements. Clearly, different species react in distinct ways to these variations. Species are also influenced by the type of development. In species with direct development, internal incubation allows individuals to overcome variations in salinity (Lozoya & Defeo, 2006; Lozoya *et al*, 2010), whereas species with indirect development are affected by salinity gradients to a greater degree, most likely due to the greater exposure of larva to these variations.

Salinity gradients are also influenced by spraying and seasonality. The increase in rainfall tends to alter the availability of fresh water in coastal environments, through precipitation. Salinity decreases during the rainy season and increases significantly during the dry season (Silva *et al*., 2011) and/or through the increase of flowing water. Some studies have shown that salinity is usually lower in beaches located in regions with a high number of rivers which flow down to the coast (Silva *et al*., 2011).

3.3 Anthropogenic Occupation and Erosion of Coastal Environments

Any structure or activity that disturbs the transport of sand in coastal environments and between these environments and the ocean, can result in the increase of erosion processes (Brown & McLachlan, 2002). Disturbances can be caused by both natural phenomena, for example storms that increase wave and wind strength, and anthropogenic action, such as mining, soft construction, dredging and unorganized occupation, principally in the backshore. The physical properties, usually measured for beach systems, such as sand aspect, size, configuration and geometry (Barnard *et al*., 2012; Harris *et al*., 2011; Ortega *et al*., 2013; Revell *et al*., 2011; Schlacher & Morrison, 2008; Schlacher *et al*., 2012; Schlacher & Thompson, 2013; Thompson & Schlacher, 2008) can be altered, de-characterizing the slope, forming a new topography, accumulating sand and creating new habitats for the biota (Dugan & Hubbard, 2010; Nordstrom *et al*., 2012) or by destroying existing habitats.

Responses of biodiversity to these alterations, especially anthropogenic alterations, are often behavioral and the study of animal behavioral changes is an adequate indicator for the evaluation of impacts in coastal environments (Schlacher *et al*., 2013; Schlacher *et al*., 2014). Responses can be different depending on the taxon. Vertebrates can react by changing environment or altering their feeding behavior patterns (Schlacher *et al*., 2013; Weston *et al*., 2014), whereas invertebrates can vary their sediment digging efforts (Manning *et al*., 2013; Viola *et al*., 2013) or by altering their distribution pattern between the shore zones. Sediment compaction caused by vehicle traffic (Schlacher & Lucrezi, 2010) or by trampling, a change in water turbidity and the eutrophication of the environment also elicits these responses. In coastal environments, the use of heavy vehicles for cleaning residues is common which, as well as causing sediment compaction, also removes organic material originating from strandings, which is an important resource for the maintenance of biodiversity as has been mentioned above.

Coastal occupation, in an unorganized manner, compromises spatial temporal dynamics and can result in an increase of erosion processes, causing a loss or fragmentation of habitats, especially in the backshore, where buildings are more common. This process can result in a change of habitat in terms of biodiversity and/or changes in the pattern of distribution of several species. The ways in which organisms react to these changes can be interpreted in order to evaluate the state of conservation of these environments, since some of the more sensitive invertebrates can be efficient for the monitoring of habitat loss (Hubbard *et al*., 2013). As these are ecosystems with a certain high trophic complexity, this role is not limited to organisms recognized as being adapted to coastal environments, such as molluscs or crustaceans. Studies on wolf-spiders (*Allocossa brasiliensis*) found on the Uruguayan coast, for example, have demonstrated that in more fragmented coastal environments, the number of burrows and specimens was reduced, mainly affecting individuals in immature stages and that the most adequate sandy habitat for *A. brasiliensis* should present an optimal vegetation coverage of 25% to 50% (Jorge *et al*., 2015). In this context, vertebrates are often underestimated, possibly due to visiting species being more commonly occurring, however, they make up a diverse fauna of fish, amphibians, reptiles, birds and mammals (Peterson *et al*., 2013). Many of these vertebrates, including those that are threatened such as marine turtles, are dependent on coastal ecosystems, as they use these environments for feeding or nesting (Maslo *et al*., 2011; Schlacher *et al*., 2013; Schlacher *et al*., 2014; Schoeman *et al*., 2014; Wallace *et al*., 2011). These relationships provide evidence of an important service provided by these ecosystems, as they offer adequate habitats that provide shelter and food for the maintenance of coastal biodiversity.

3.4 Commitment to Ecosystem Services

Coastal ecosystem characteristics do not only come from the strong influence of ocean dynamics. Beaches, are areas of transition and therefore, also suffer interference from the continent, receiving organic material coming from the backshore, from dunes or from being carried by rains or rivers which flow along the coast. These characteristics make sandy shores important and delicate ecosystems that, when in equilibrium, can provide several services, many essential to the human race, such as the protection of coastal areas, fishing and bait collection (Gattuso *et al*., 2015; Brown & McLachlan, 2002). In a less obvious way, the regulation of several ecological processes is also important, especially the flow of material and energy between the coast, from the dunes and backshore to the sublittoral zone, considering underlying trophic levels (Brown & McLachlan, 2002), including oceans.

Furthermore, sandy shores are equipped with great scenic beauty which results in these environments becoming areas of recreation and leisure, provoking their unorganized use, without adequate evaluation for their load capacities and the irresponsible occupation of the backshore. From the point of view of future climate change, erosion pressure is predicted to increase on the backshore and in nearby environments, such as the dune system, as these environments can expand vertically and laterally in response to the SLR (Oppenheimer et al, 2019). As there is a great movement of sediments with this process, the movement of coastal areas towards the continent is also expected, with an obvious monitoring and adaptation of biodiversity and trophic flows. In addition to the SLR forecasts (IPC, 2013; Oppenheimer et al, 2019), the transversal migration of the beach profile can be stimulated by wave energy or by the momentary rise in sea level because of storms. Disordered occupation, the presence of buildings and other human actions also impact these ecosystems, restricting the migration of the coastal profile towards the continent, causing these environments to lose their progressive capacity to adapt and fail to provide important services, including the formation of protection barriers (Oppenheimer et al, 2019) resulting in increased coastal erosion, the disappearance of the backshore (Souza, 2009) (Figure 3) and the compromise of fundamental services, such as those for biodiversity habitat and those for regulation and provision, affecting the trophic chains along the coast.

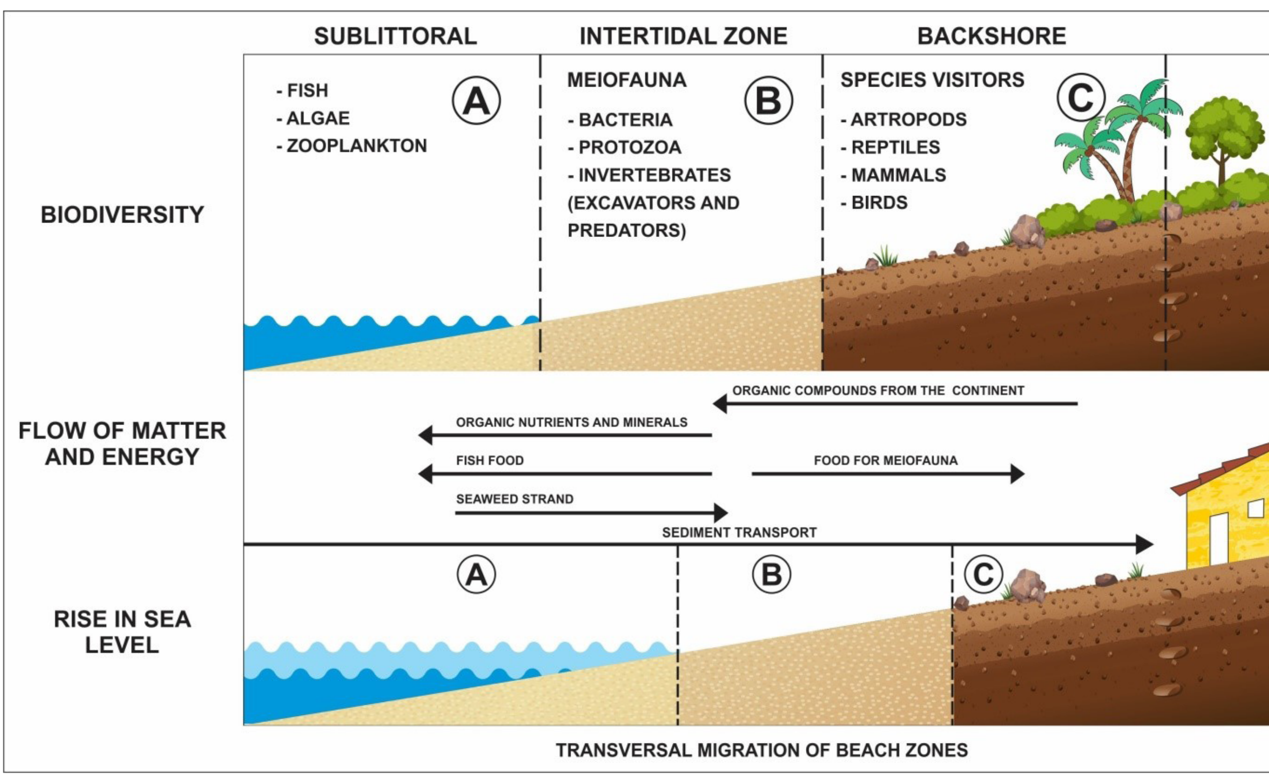

Figure 3 Trophic and sedimentary dynamics in a dissipative beach with backshore occupation (C) and sediment movement, resulting in the transversal migration of beach zones, influenced by storms and increased sea levels (figure developed by the author based on data by Brown & McLachlan (2002) on the food network on a sandy beach and the discussions by Oppenheimer *et al* (2019) on the lateral displacement of beaches in response to the SLR).

With the possible disappearance of the backshore, comes the loss of coastal functionality. The break in ecosystem dynamic compromises services provided by these environments, since, as well as losing space created for recreation and leisure for human populations, coastal protection (Gattuso *et al*., 2015) and ecosystem balance is also lost. With the destruction of several habitats and the interruption of trophic flow, many species that use coastal ecosystems for feeding, shelter and nesting may migrate or disappear. Biodiversity responds relatively well to physical climate pressures however, these pressures require a balanced environment in order for them to adapt according to the capacity of each taxon.

Another aggravating factor is that a large part of the world's population is concentrated in coastal environments, resulting in the increase of anthropogenic pressure on coastal ecosystems. Martínez *et al*. (2007), identified that in 84% of all the countries in the world that have coasts, a large percentage of their population (80% and 100%) live within at least 100km of the coast and it is expected that this number will rise over future decades (Neumann *et al*., 2015; Fernandino *et al*., 2018).

With this panorama of future climate changes, the increase of erosion processes and the growth of the human population along coastal environments, arises several challenges for coastal management on a global scale. Fundamentally, according to Schlacher *et al* (2014), the challenges associated with beach management come from the duality of their purpose: beaches need to function as areas of intense recreation and other human uses and also need to be conserved, since they act as habitats and unique ecosystems that require protection from excessive use (McLachlan *et al*., 2013). Schlacher *et al* (2014), further points out that traditional methods of beach management focus almost exclusively on restoring sand budgets for the maintenance of beach width and protecting human infrastructure (Nordstrom *et al*. 2012; Schlacher *et al*., 2014) and that, on the other hand, the conservation of habitats, species and ecological functions are often considered less important or technically inadequate (Peterson *et al*., 2013). It is therefore, necessary that new parameters that avoid conflict of use, also use biodiversity and the maintenance of environmental balance as management tools. Prioritizing the functionality of ecosystems would guarantee the maintenance of several services that coastal ecosystems offer, including those essential to human populations, such as food, fishing, bait collection, recreation and leisure.

4 Conclusions

The spatial distribution of biodiversity on sandy shores is particularly sensitive to natural changes which are principally induced by wave energy, which can be altered with the occurrence of storms and wind action. Species diversity and abundance are directly related to factors associated with morphodynamics, such as shore inclination and especially sediment particle size. Other factors, such as salinity, also influence coastal ecosystems which can be an important parameter in submitting organisms to osmotic stress.

In coastal zones, sediments are subject to seasonal accretion and erosion events, related to rainfall patterns and the occurrence of storms, which can alter the occurrence and distribution of some benthic taxa. The occurrence of organic strandings, especially macrophytes, should be considered as an important factor in ecological studies of sandy shores, particularly in reflective beaches, and the constant cleaning of these resources can substantially impact trophic flow. Dissipative beaches have greater trophic complexities, with a greater presence of predators in more advanced trophic levels. The dynamics of some taxa are already known however, little is known about the importance of microbes in the surf zone and the use of interstitial space which recycles nutrients for upper trophic levels, including marine ecosystems.

Other than their ecological complexity and the importance of their biodiversity, sandy beach value and environmental functions are often perceived as secondary in relation to their economic and recreational values. This may be due to the fact that ecological studies on sandy shores are still in their early stages and that many broad principles on beach ecology have only recently been articulated. The lack of such information can make it difficult to adequately manage these ecosystems. It is therefore, necessary to carry out more studies on beach biodiversity dynamics and how their reaction influences morphodynamic and climate factors, with the aim of creating more adequate strategies for the conservation of coastal ecosystems and for the maintenance of their services.

It is also necessary to identify efficient biological indicators within the context of ecological communities, aiming to maintain ecosystem balance. The actions promoted, especially by public institutes responsible for the management of coastal environments, have no information on which indicators should be used for the adequate management of these environments and commonly prioritize the occupation of these environments for recreation and leisure activities.

The need for a more effective coastal management system, which guarantees biodiversity conservation, ecosystem balance and maintenance of its services including those essential to the human race, is a challenge. The current systems are generally sustained by empirical data and the selection of parameters and methods, involving biodiversity, to precisely measure the condition of these systems and the ecological effects of anthropogenic activities, is a complex task. It is therefore, necessary to invest more heavily in studies on coastal ecosystem dynamics, principally, in relation to global climate changes and the intensification of coastal occupation by humans. Preserving the functionality of these ecosystems is to guarantee, not only the maintenance of biodiversity, but also to allow them to sustain their services, which are directly related to the maintenance of the quality of life of human beings.

5 References

Alberto, R.M.F. & Fontoura, N.F. 1999. Distribuição e estrutura etária de *Ocypode quadrata* (Fabricius, 1787) (Crustacea, Decapoda, Ocypodidae) em praia arenosa do litoral sul do Brasil. *Revista Brasileira de Biologia*, *59*(1): 95-108.

Alves, E. dos S., & Pezzuto, PR. 2009. Efeito de frentes frias na macrofauna bentônica de praias arenosas expostas com morfodinâmica contrastante. *Revista Brasileira de Oceanografia*, *57* (2), 73-94.

Atrill, M.A. 2002. A testable linear model for diversity trends in estuaries. *Journal of Animal Ecology*, *71*: 262–269.

Barnard, P.L.; Hubbard, D.M. & Dugan, J.E. 2012. Beach response dynamics of a litoral cell using a 17-year single-point time series of sand thickness. *Geomorphology*, 139-140, 588-598.

Barboza, F.R.; Gómez, J.; Lercari D. & Defeo, O. 2012. Disentangling Diversity Patterns in sandy Beaches along Environmental Gradients. *PLoS ONE*, 7(7).

Bentes A.M.L., Fernandez G.B., Ribeiro A.Y. 1997. Estudo da morfodinaˆmica de praias compreendidas entre Saquarema e Macae´, RJ. Oecologia Brasiliensis, 3, 229–243.

Blankensteyn, A. 2006. O uso do caranguejo maria-farinha *Ocypode quadrata* (Fabricius, 1787) (Crustacea, Ocypodidae) como indicador de impactos antropogênicos em praias arenosas da Ilha de Santa Catarina, Santa Catarin - Brasil. *Revista Brasileira de Zoologia,* 23 (3): 870-876.

Bremec, C; Carcedo, C; Piccolo, M., Dos Santos, E. & Fiori, S. 2013. *Sabellaria nanella* (Sabellariidae): from solitary subtidal to intertidal reef-building worm at Monte Hermoso, Argentina (39° S, south-west Atlantic). *Journal of the Marine Biological Association of the United Kingdom*, 1:1 - 6.

Brown, A.C., McLachlan, A. 1990. Ecology of Sandy Shores. Elsevier, Amsterdam, 328 pp.

Brown, A.C. & Mclachlan, A. 2002. Sandy shore ecosystems and the threats facing them: some predictions for the year 2025. *Environmental Conservation, 29*(1): 62–77.

Calliari, L.J., Klein, A.H.F., 1993. Características Morfodinâmicas e Sedimentológicas das Praias Oceânicas entre Rio Grande e Chuí, RS. Pesquisas, 20 (1), pp. 48-56.

Calliari, L.J.; Muehc, D.; Gemael Hoefel, F.G. & Toldo Jr., E. 2003. Morfodinâmica praial: uma breve revisão (Beach morphodynamics: a brief review). *Revista brasileira, oceanografia*, 5l: 63-78.

Caló, J.; Fernandez, E.; Marcos, A. & Aldacour, H. 2005. Observaciones litorales ambientales de olas, corrientes y vientos de la playa de Monte Hermoso entre 1996 y 1999. *Geoacta, 30*: 27–38.

Carcedo, C.; Fiori, S. & Bremec, C. 2014. Macrobenthic surf zone communities of temperate Sandy beaches: spatial and temporal patterns. *Marine Ecology, 36*: 326–336.

Cestari, C.O. 2008. Uso de praias arenosas com diferentes concentrações humanas por espécies de aves limícolas (Charadriidae e Scolopacidae) neárticas no sudeste do Brasil. *Biota Neotropica, 8*(4): 083-088. Available in <http://www.biotaneotropica.org.br>. Access in: 08 Sept, 2018.

Cochôa, A.R.; Lorenzi. L. & Borzone, C.A. 2006. A influência da passagem de uma frente meteorológica na distribuição da macrofauna bentônica mesolitoral de uma praia arenosa exposta. *Tropical Oceanography*, 34, n. 2, 59-71.

Corte, N.C.; Schlacher, T.A.; Checon, H.H,; Barboza, C.A.M.; Siegle, E.; Coleman, R.A. & Amaral, A.C.Z. 2017. Storm effects on intertidal invertebrates: increased beta diversity of few individuals and species. *PeerJ*, *5*: e3360. Available in <https://peerj.com>. Access in: 01 jun, 2018.

Coutinho, M.S. 2013. Diversidade da macrofauna bentônica de praias arenosas na APA Costa das Algas-ES, Brasil. UFES, Vitória. Available in < http://www.oceanografia.ufes.br>. Access in: 01 Sept, 2018.

Defeo O. & McLachlan A. 2005. Patterns, processes and regulatory mechanisms in sandy beach macrofauna: a multiscale analysis. *Marine Ecology Progress Series*, 295, 1–20.

Degraer, S.; Volckaert, A. & Vincx, M. 2003. Macrobenthic. zonation patterns along a morphodynamical continuum of macrotidal, low tide bar/rip and ultra-dissipative sandy beaches. *Estuarine, Coastal and Shelf Science*, *56*(3): 459–468.

Dobrynin, M.; Murawski, J.; Baehr, J. & Ilyina, T. 2015. Detection and attribution of climate change signal in ocean Wind waves. *Journal of Climate*, *28*: 578-597.

Dugan, J. E.; Hubbardb, D.M.; Mccraryc, M.D. & Piersonc, M.O. 2003. The response of macrofauna communities and shorebirds to macrophyte wrack subsidies on exposed Sandy beaches of southern California. *Estuarine, Coastal and Shelf Science*, *58S*: 25–40.

Elías, R.; Iribarne, O.; Bremec, C. & Martinez, D. 2007. Comunidades bentónicas de fondos blandos. *In:* PÍCCOLO, M.C. & HOFFMEYER, M.S. (Eds.), *El ecosistema del estuario de Bahıa Blanca*. Instituto Argentino de Oceanografıa, p. 281– 340.

Fernandino, G.; Elliff, C. & Reimão Silva, I. 2018. Ecosystem-based management of coastal zones in face of climatechange impacts: Challenges and inequalities. *Journal of Environmental Management*, *215*: 32 - 39.

Gallucci, F. & Netto, S.A. 2004. Effects of the passage of cold fronts over a coastal site: na ecosystem approach. *Marine Ecology Progress Series*, *281*: 79-92.

Gattuso, J.P.; Magnan, A.; Billé, R.; Cheung, W.W,L.; Howes EL.; Joos, F.; Allemand, D.; Bopp, L.; Cooley, S.R.; Eakin, C.M.; Hoegh-Guldberg, O.; Kelly, R.P.; Pörtner, H.O.; Rogers, A.D.; Baxter, J.M.; Laffoley, D.; Osborn, D.; Rankovic, A.; Rochette, J.; Sumaila, U.R.; Treyer, S. & Turley, C. 2015. Contrasting futures for ocean and society from different anthropogenic CO2 emissions scenarios. *Science*, *349*(6243): aac 4722.

Gibbins, C.; Vericat, D. & Batalla, R.J. 2007. When is stream invertebrate drift catastrophic? The role of hydraulics and sediment transport in initiating drift during flood events. *Freshwater Biology*, *52*: 2369–2384.

Harris, L.; Nel, R. & Schoeman, D. 2011. Mapping beach morphodynamics remotely: a novel application tested on South African sandy shores. *Estuarine Coastal and Shelf Science*, *92*: 78-89.

Harris, L.; Nel, R.; Smale, M. & Schoeman, D. 2011. Swashed away? Storm impacts on Sandy beach macrofaunal communities. *Estuarine Coastal and Shelf Science*, *94*:210-221.

HOEFEL, F.G. 1998. Morfologia de praias arenosas oceânicas: uma revisão bibliográfica. Itajaí: Editora da Univali.

Hoffmeyer, M.; Mianzan, H. 2007. Macro-zooplancton del estuario y aguas costeras adyacentes. In: PICCOLO, M.C.; HOFFMEYER, M.S. (Eds*.), El ecosistema del estuario de Bahıa Blanca*. Instituto Argentino de Oceanografıa, p. 143–151.

Hubbard, D.M.; Dugan, J.E.; Schooler, N.K. &Viola, S.M. 2013. Local extirpations and regional declines of endemic upper beach invertebrates in southern California. *Estuarine, Coastal and Shelf Science*, *150*: 67-75

IPCC. 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

Jaramillo, E.; Croker, R.A. & Hatfield, E.B. 1987. Long-term structure, disturbance, and recolonization of macroinfauna in a New Hampshire sand beach. *Canadian Journal of Zoology*, *65*:3024-3031

Jaramillo, E.; Contreras, H.; Duarte, C. & Quijón, P. 2001. Relationships Between Community Structure of the Intertidal Macroinfauna and Sandy Beach Characteristics Along the Chilean Coast. *Marine Ecology*, *22*(4): 323-342

Jorge, C.; Laborda, A.; Alves Días; M.; Aisenberg, A.& Simó, M. 2015. Habitat Preference and Effects of Coastal Fragmentation in the Sand-Dwelling Spider *Allocosa brasiliensis* (Lycosidae, Allocosinae) *Open Journal of Animal Sciences*, *5*: 309-324.

Koerner, K.F; Oliveira, U.R & Gonçalves, G. 2013. Efeito de estruturas de contenção à erosão costeira sobre a linha de costa: Balneário Hermenegildo, Rio Grande do Sul, Brasil * Effect of coastal erosion contention structures on the coastline: Hermenegildo Beach, Rio Grande do Sul, Brazil *Revista da Gestão Costeira Integrada - Journal of Integrated Coastal Zone Management 13*(4):457-471.

Lamour, M. R. & Soares, C. R. 2003. Sedimentary variation and volumetric balance in 4 beaches in north littoral of Santa Catarina State, Brazil, in a La. Niña/El Niño Period. *Journal of Coastal Research*, SI35: 216-220.

Lercari, D. & Defeo, O. 1999. Effects of freshwater discharge in sandy beach populations: the mole crab *Emerita brasiliensis* in Uruguay. *Estuarine, Coastal and Shelf Science* 49: 457–468.

Lercari, D.; Bergamino, L. & Defeo, O. 2010. Trophic models in sandy beaches with contrasting morphodynamics: Comparing ecosystem structure and biomass flow. *Ecological Modelling*, *221*: 2751–2759.

Lozoya, J.P. & Defeo, O. 2006. Effects of a freshwater canal discharge on na ovoviviparous isopod inhabiting an exposed sandy beach. *Marine and Freshwater Research*, *57*(4): 421-428.

Lozoya, J.P; Gómez, J. & Defeo, O. 2010. Modelling large-scale effects of estuarine and morphodynamic gradients on distribution and abundance of the Sandy beach isopod Excirolana armata. *Estuarine, Coastal and Shelf Science*, *87*: 472–478.

Lucrezi, S.; Schlacher, T.A. & Robinson, W. 2010. Can storms and shore armouring exert additive effects on sandy-beach habitats and biota? *Marine and Freshwater Research*, *61*:951-962.

Luzzatto, D.C. 2006. The biology and ecology of the giant free egg capsules of *Adelomelon brasiliana* Lamarck, 1811 (Gastropoda: Volutidae). *Malacologia*, *49*: 107–119.

Machado, P.M.; Costa, L.L.; Suciu, M.C.; Tavares, D.C. & Zalmon, I.R. 2016. Extreme storm wave influence on sandy beach macrofauna with distinct human pressures. *Marine Pollution Bulletin*, *107*(1):125-135.

Manning, L.M.; Peterson, C.H. & Fegley, S.R. 2013. Degradation of surf-fish foraging habitat driven by persistent sedimentological modifications caused by beach nourishment. *Bulletin of Marine Science, 89*: 83-106.

Martínez, M.L., Intralawan, A., Vazquez, G., Perez-Maqueo, O., Sutton, P., Landgrave, R. 2007. The coasts of our world: ecological, economic and social importance. *Ecol. Econ*. 63, 254e272.

Maslo, B.; Handel, S.N. & Pover, T. 2011. Restoring beaches for Atlantic coast piping plovers (*Charadrius melodus*): a classification and regression tree analysis of nest-site selection. *Restoration Ecololy, 19*: 194-203.

Masselink, G. & Short, A.D. 1993. The Effect of Tide Range on Beach Morphodynamics and Morphology: A Conceptual Beach Model. *Journal of Coastal Research*, 9: 785-800.

Mateo, M.A. & Garcia-Rubies, T. 2012. Assessment of the ecological impact of the extreme storm of Sant Esteve's Day (26 December 2008) on the littoral ecosystems of the north Mediterranean Spanish coasts. *Final Report (PIEC 200430E599)*. Available in <http://www2.ceab.csic.es/GAME/Sant_Esteve_Storm/HOME.html> . Access in 03 May, 2018.

McClain, C.R. & Schlacher, T.A. 2015. On some hypotheses of diversity of animal life at great depths on the sea floor. *Marine Ecology*, *36*:849-872

Mclachlan, A. & Brown, A. 2006. The Ecology of Sandy Shores. Burlington, Elsevier-Academic Press. 387 p.

McInnes, K.; Erwin, T.A. & Bathols, J.M., 2011. Global climate model projected changes in 10 m wind speed and direction due to anthropogenic climate change. A*tmospheric Science Letters*, *12*: 325-333.

Muniain, C.; Ardila, N.E. & Cervera, J.L. 2007. Pleurobranchaea inconspicua Bergh, 1897 (Opisthobranchia: Pleurobranchidae): Redescription and distribution from Argentina and Colombia. *Bonner Zoologische Beitrëage Band*, *55*: 291–300.

Negrello Filho, O.A. & Lana, P.C. 2013. Short-term stability of estuarine benthic assemblages: are storms pattern-defining events? *Zoologia*, *30*: 266-272.

Neumann, B., Vafeidis, A.T., Zimmermann, J., Nicholls, R.J. 2015. Future coastal population growth and exposure to sea-level rise and coastal flooding e a global assessment. *Plos One* 10, e0118571.

Nordstrom, K.F.; Jackson, N.L.; Freestone, A.L.; Koroticy, K.H. & Puleo, J.A., 2012. Effects of beach raking and sand fences on dune dimensions and morphology. *Geomorphology*, *179*: 106-115.

Nucci, P.R.; Turra, A. & Morgado, E.H. 2001. Diversity and distribution of crustaceans from 13 sheltered sandy beaches along São Sebastião Channel, south-eastern Brazil. *Journal of the Marine Biological,* 81: 475-484.

Oppenheimer, M.B.C.; Glavovic , J.; Hinkel, R.; van de Wal, A.K.; Magnan, A.; Abd-Elgawad, R.; Cai, M.; Cifuentes-Jara, R.M.; DeConto, T.; Ghosh, J.; Hay, F.; Isla, B.; Marzeion, B.; Meyssignac, & Sebesvari, Z. 2019: Sea Level Rise and Implications for Low-Lying Islands, Coasts and Communities. In*: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate* [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. In press.

Ortega C.K.; Smit, A.J.; Laudien, J. & Schoeman, D.S. 2011. Complex, dynamic combination of physical, chemical and nutritional variables controls spatio-temporal variation of sandy beach community structure. *PloS One*, *6*(8): e23724.

Ortega, L.; Celentano, E.; Finkl, C. & Defeo, O. 2013. Effects of climate variability on the morphodynamics of Uruguayan sandy beaches. *Journal Coastal Research*, *29*: 747-755.

Pagliosa, P.R. 2006. Distribuição da macrofauna bêntica do entremarés ao sublitoral em uma praia estuarina da Baía da Babitonga, Sul do Brasil. *Biotemas*, *19*(1): 25.

Pearson, T. & Rosenberg, R. 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. *Oceanography and Marine Biology Annual Review*, *16*: 229-311.

Perillo, G.M.E.; Piccolo, M.C.; Parodi, E. & Freije, R.H. 2000. The Bahia Blanca Estuary, Argentina. *In:* SEELIGER U., KJERFVE B. (Eds.). *Coastal Marine Ecosystems of Latin America. Environmental Science Series*. Springer Verlag, Berlin, p 205–217.

Peterson, C.H.; Fegley, S.R.; Voss, C.M.; Marschhauser, S.R. & VanDusen, B.M. 2013. Conservation implications of density-dependent predation by ghost crabs on hatchling sea turtles running the gauntlet to the sea. *Marine Biology*, *160*: 629-640.

Revell, D.L.; Dugan, J.E. & Hubbard, D.M. 2011. Physical and ecological responses of sandy beaches to the 1997e 98 El Niño. *Journal Coastal Research*, *27*: 718-730.

Rodil, I.F. & Lastra, M. 2004. Environmental factors affecting benthic macrofauna along a gradient of intermediate sandy beaches in northern Spain. *Estuarine, Coastal and Shelf Science*, *61*: 37- 44.

Semedo, A.; Weisse, R.; Behrens, A.; Sterl, A.; Bengtsson, L. & Gunther, H. 2013. Projection of global wave climate change toward the end of the twenty-first century. *Journal of Climate*, *26*: 8269-8288.

Schlacher, T.A.; Noriega, R.; Jones, A. & Dye, T. 2012. The effects of beach nourishment on benthic invertebrates in eastern Australia: impacts and variable recovery. *The Science of the Total Environment*, *435*: 411-417.

Schlacher, T.A.; Nielsen, T. & Weston, M.A. 2013. Human recreation alters behaviour profiles of non-breeding birds on open-coast sandy shores. *Estuarine, Coastal and Shelf Science*, *118*: 31-42.

Schlacher, T.A. & Lucrezi, S. 2010. Compression of home ranges in ghost crabs on sandy beaches impacted by vehicle traffic. *Marine Biology*, *157*: 2467-2474.

Schlacher, T.A. & Morrison, J.M. 2008. Beach disturbance caused by off-road vehicles (ORVs) on sandy shores: relationship with traffic volumes and a new method to quantify impacts using image-based data acquisition and analysis. *Mariner Pollution Bulletin*, *56*: 1646-1649.

Schlacher, T.A. & Thompson, L. 2013. Environmental control of community organisation on ocean-exposed sandy beaches. *Marine and Freshwater Research*, *64*:119-129.

Schlacher, T.A.; Schoeman, D.S.; Jones, A.R.; Dugan, J.E.; Hubbard, D.M.; Defeo, O.; Peterson, C.H.; Weston, M.A.; Maslo, B.; D. Olds, Felicita Scapini. F.; Nel, R.; Harris, L.R.; Lucrezi, S.; Lastra, M.; Huijbers, C.M. & Rod, M. 2014. Metrics to assess ecological condition, change, and impacts in sandy beach ecosystems. *Connolly Journal of Environmental Management*, *144*: 322-335.

Schlacher, T.A.; Weston, M.A.; Schoeman, D.S.; Olds A.D.; Huijbers, C.M. & Connolly, R.M. 2015. Golden opportunities: a horizon scan to expand sandy beach ecology. *Estuarine, Coastal and Shelf Science*, *157*:1-6.

Schoeman, D.S. & Richardson, A.J. 2002. Investigating biotic and abiotic factors affecting the recruitment of an intertidal clam on an exposed sandy beach using a generalized additive model. *Journal of Experimental Marine Biology and Ecology*, *276*: 67–81.

Schoeman, D.S.; Schlacher, T.A. & Defeo, O. 2014. Climate-change impacts on sandy beach biota: crossing a line in the sand. *Global Change Biology*, *20*(8):2383-2392.

Silva, N.I.S.; Pereira, L.C.C.; Gorayeb, A.; Vila-Concejo, A.; Sousa, R.C.; Asp, N.E. & Costa, R.M. 2011. Natural and social conditions of Princesa, a macrotidal sandy beach on the Amazon Coast of Brazil. *Journal of Coastal Research*, *64*:1979-1983.

Souza, C.R.G. 2009. A Erosão Costeira e os Desafios da Gestão Costeira no Brasil. *Revista de Gestão Costeira Integrada*, *9*: 17-37.

Sydeman,W.J.; García-Reyes, M.; Schoeman, D.S.; Rykaczewski, R.R.; Thompson, S.A.; Black, B.A. & Bogard, S.J. 2014. Climate change and wind intensification in coastal upwelling ecosystems. *Science*, *345*: 77-80.

Thompson, L.M.C. & Schlacher, T.A. 2008. Physical damage to coastal foredunes and ecological impacts caused by vehicle tracks associated with beach camping onsandy shores: a case study from Fraser Island, Australia. *Journal of Coastal Conservation*, *12*: 67-82.

Urabe, J.; Suzuki, T.; Nishita, T. & Makino, W. 2013. Immediate ecological impacts of the 2011 Tohoku earthquake tsunami on intertidal flat communities. *PLOS ONE 8*(5):e62779

Veloso, V.G.; Cardoso, R.S. & Fonseca, D.B. 1997. Adaptações e biologia da macrofauna de praias arenosas expostas com ênfase nas espécies da região entre-marés do litoral fluminense. *Oecologia brasiliensis*, *3*: 121-133.

Vilar de Araujo, C.C.; Melo Rosa, D. & Fernandes, J.M. 2008. Densidade e distribuição espacial do caranguejo *Ocypode quadrata* (Fabricius, 1787) (Crustacea, Ocypodidae) em três praias arenosas do Espírito Santo, Brasil. *Biotemas*, *21*: 73-80.

VILLWOCK, J.A. 1994. A Costa Brasileira: Geologia e Evolução. *Anais III Simpósio de Ecossistemas da Costa Brasileira - Subsídios a um Gerenciamento Ambiental*, Publ. ACIESP, São Paulo, 3(87): 1-15.

Viola, S.M.; Hubbard, D.M.; Dugan, J.E. & Schooler, N.K. 2013. Burrowing inhibition by fine textured beach fill: implications for recovery of beach ecosystems. *Estuarine, Coastal and Shelf Science*, *150*(A): 142-148.

Wallace, B.P.; DiMatteo, A.D.; Bolten, A.B.; Chaloupka, M.Y.; Hutchinson, B.J.; Abreu- Grobois, F.A.; Mortimer, J.A.; Seminoff, J.A.; Amorocho, D.; Bjorndal, K.A.; Bourjea, J.; Bowen, B.W.; Dueñas, R.; Casale, P.; Choudhury, B.C.; Costa, A.; Dutton, P.H.; Fallabrino, A.; Finkbeiner, E.M.; Girard, A.; Girondot, M.; Hamann, M.; Hurley, B.J.; Lopez-Mendilaharsu, M.; Marcovaldi, M.A.; Musick, J.A.; Nel, R.; Pilcher, N.J.; Tro€eng, S.; Witherington, B. & Mast, R.B. 2011. Global conservation priorities for Marine turtles. *PLoS One,* 6.

Weston, M.A.; Schlacher, T.A. & Lynn, D. 2014. Pro-environmental beach driving is uncommon and ineffective in reducing disturbance to beach-dwelling birds. *Environmental Managemente*, *53*: 999-1004.

Wright, L.D. & Short, A.D. 1983. Morphodynamics of beaches and surf zones in Australia. In: Komar, P.D. (ed.). *Handbook of Coastal Process and Erosion*. CRC Press, Boca Raton, 35- 66.

Wright, L.D. & Short, A.D. 1984. Morphodynamic variability of surf zones and beaches: a synthesis. *Marine Geology*, *58*: 93–118.

Received: 1 August 2020

Accepted: 4 December 2020

How to cite:

Carvalho, A.A.F & Silva, I.R. 2021. Morphodynamic and Climatic Control on Sandy Beaches: Challenges of Geoenvironmental Studies for the Conservation of Biodiversity and the Maintenance of Ecosystem Services. *Anuário do Instituto de Geociências, 44*: 36999. DOI 1982-3908_2021_44_36999